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New Aerial Herbicide Application Technology

FPM 95-5
January 1995

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Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

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NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.



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NEW AERIAL HERBICIDE APPLICATION TECHNOLOGY¹

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PURPOSE AND SCOPE

The purpose of this paper is to present a review of aerial application technology with focus on herbicides application to forests in California. The paper does not cover, except in general terms, the use and effectiveness of specific herbicide. The paper, and its accompanying presentation, are organized into six main parts: Introduction; Technology Needs; State-of-the-Art; New Technology; Developing Technology; and Summary of Drift Reduction Methods.

INTRODUCTION

Background

Of the primary methods (thermal, physical, chemical and biological) of controlling vegetation, chemicals applied by helicopters remains, in most cases, one of the most cost effective method for site preparation and release from competition. Biocontrol of forest weeds using microbials and insects is a promising technology; however, present work is directed primarily at agricultural and range pest vegetation (Dorworth 1992; Hall and Barry 1995). Helicopter application of herbicides to forests is unpopular with some sectors of the public and consequently with some land managers. In addition to its unpopularity, and often misunderstandings, of herbicides and herbicide use in general, resource managers have to deal with the negative perceptions associated with spray helicopters, especially those operating over public forest lands. We are all too familiar with the numerous legal challenges that the U. S. government has had to defend over the past two decades, noting that from 30 March 1984 to 7 January 1991 aerial application of herbicides was deferred in the Pacific Southwest Region (R-5). Nevertheless, the USDA Forest Service is a minor user of pesticides, using less than 0.1 percent of the pesticides (herbicides are just one of the many categories of pesticides) used for all purposes by all people in the United States (USDA Forest Service 1993a). After exhaustive environmental analysis, aerial application of chemical herbicides survives as one of the methods of applying herbicides to control competing vegetation in forests of California.

Another question being asked today is what role might herbicides have in ecosystem management (USDA Forest Service 1993b). Some would suggest none, while others would offer the use of herbicide to restore habitats destroyed by man, fire, and flood; to restore and maintain biodiversity; and to control exotic vegetation that threatens the ecosystems we are helpless at protecting through natural processes. McMahon et al. (1993) offer additional thoughts on herbicides as a tool in ecosystem management.

The value and need for effective and safe herbicides for forestry use are indisputable to the authors. The continuing challenge is the need to support, through public and private partnerships, the development of new vegetation control methodologies including biological control and chemical herbicides; to educate the resource manager, applicator and the public; to promote their safe and environmentally sound use; and to monitor, in a scientifically sound manner, their use, failures and successes, such as supported by the National Council of the Paper Industry for the Air and Stream Improvement, Inc. (Ice 1994).

California Code of Regulations

The State of California has a rather specific code (State of California 1990) regulating pesticide use. In addition, the county agricultural commissioners may impose additional controls. As part of the project planning process, applicators review the code, contact the county agricultural commissioner, and review the herbicide label. Below we quote from Section 6460, pages 397-

398 of the California Code of Regulations, Title 3, Food and Agriculture, a portion that pertains to aerial application of herbicides. The quote, as numbered, follows:

"6460. Drift Control.

Unless expressly authorized by permit issued pursuant to section 6412, no liquid herbicide specified in subsection (m) of section 6400 shall be:

- (a) Discharged more than ten feet above the crop or target. Discharge shall be shut off whenever it is necessary to raise the equipment over obstacles such as trees or poles.
- (b) Applied when wind velocity is more than ten miles per hour.
- (c) Applied by aircraft except as follows:
 - (1) The flow of liquid to aircraft nozzles shall be controlled by a positive shutoff system as follows:
 - (A) Each individual nozzle shall be equipped with a check valve and the flow controlled by a suckback device or a boom pressure release device; or
 - (B) Each individual nozzle shall be equipped with a positive action valve.
 - (2) Aircraft nozzles shall not be equipped with any device or mechanism which would cause a sheet, cone, fan, or similar type dispersion of the discharged material except as otherwise provided.
 - (3) Aircraft boom pressure shall not exceed 40 pounds per square inch.
 - (4) Aircraft nozzles shall be equipped with orifices directed backward parallel to the horizontal axis of the aircraft in flight.
 - (5) Fixed wing aircraft and helicopters operating in excess of 60 miles per hour shall be equipped with jet nozzles having an orifice of not less than 1/16 inch in diameter.
 - (6) Helicopters operating at 60 miles per hour or less shall be equipped with:
 - (A) Nozzles having an orifice not less than 1/16 inch in diameter. A number 46 (or equivalent) or larger whirlplate may be used; or
 - (13) Fan nozzles with a fan angle number not larger than 80 degrees and a flow rate not less than one gallon per minute at 40 pounds per square inch pressure (or equivalent); or
 - (B) The Microfoil (R) boom (a coordinated spray system including air-foil-shaped nozzles with each orifice not less than 0.013 inches in diameter) or equivalent type approved by the director. Orifices shall be directed backward parallel to the horizontal axis of the aircraft in flight."

TECHNOLOGY NEEDS

Research on aerial application of herbicides was generally phased-out by the USDA Forest Service by 1980 (Stewart and Gratkowski 1976). Research needs resulting from environmental concerns, needs to increase reforestation and forest productivity, and new herbicide formulations that were not understood, began to mount. Barry (1984) reviewed the state-of-the-art of applying herbicides to forests, and the USDA Forest Service has reviewed and reported annually its application needs (Thomas and Ruttly 1994), even though there is no active USDA Forest Service application research program. Fortunately in the West, Mike Newton, Ed Fredrickson (Fredrickson and Newton 1993) and Logan Norris (Norris 1981) at Oregon State University, and others, pursued research in forests of the Northwest (Mike and Ed on efficacy and Logan on environmental fate), but few were pursuing specific aerial application needs. This deficiency was evaluated by Canada's National Research Institute and by the Canadian Forest Service Forest Pest Research Institute. To their credit an international survey was conducted to identify the most pressing needs and priorities of forestry herbicide application research (Campbell and Howard 1993). We believe that their summary, quoted below, well describes the needs in North America:

"A survey was conducted to determine research priorities for forest herbicide application technology research. It was sent to persons, primarily in Canada and the United States, with an interest in the topic (users, applicators, researchers and regulators). Respondents indicated support for both aerial and ground application technology research. The top ten priorities of all respondents combined for future herbicide application technology research were as follows: (1) determine appropriate scientifically-based buffer zones, (2) develop technology to allow the same efficacy with reduced active ingredient, (3) develop technology to allow the same efficacy with reduced spray volume, (4) determine the optimum drop size with regard to efficacy and drift, (5) improve "rainfastness" (resistance to spray deposit to being washed off by rain) of herbicides, (6) determine the effect of atmospheric stability and wind on herbicide drift, (7) determine the dose-response curve for environmental impact vs herbicide deposit, (8) determine the effect of temperature and relative humidity on deposit and efficacy, (9) develop atomizers capable of emitting narrow drop size spectra regardless of aircraft speed, and (10) determine the effect of temperature and relative humidity on drift. The problem of determining how to develop public support for aerial application of herbicides in forestry, although not really an application technology problem, ranked number one for Canadian users and aerial applicators, and number four for U. S. users."

To be encouraged, we will review under Developing Technology progress in addressing some of the needs identified above.

STATE-OF-THE-ART IN CALIFORNIA

The state-of-the-art of applying herbicides by air to California forests is best summarized by presenting information provided by Norm Parker, Western Helicopter, Newburg, OR (Barry 1994). Western Helicopters has been under contract to treat both private and public forest lands in California for site preparation and conifer release since 1968 and 1967 respectively.

Helicopters

Bell 47 G3 B1 with Soloy turbine engine

Hiller 12E with Soloy turbine engine

Cost of the helicopters is in the \$150,000 to \$200,000 range, while the larger helicopters such as the Hughes 500 and Bell 205 Jet Ranger (with passenger capability) are in the \$400,000 to \$600,000 range.

Both have a payload of 80-100 gallons depending upon size and elevation of helispot relative to elevation of the treatment blocks.

Operational Parameters

Spray height above terrain	25 feet subject to snags, trees, and other obstacles
Spray speed	40-50 mph
Swath width (lane separation)	40 feet, single fly, no double or cross swathing
Application rate	10 gallons per acre
System flowrate	40.4 gallons per minute
Spray system	Airfoil boom, check valve nozzles, hydraulic pump
Nozzles	Tee Jet 4664 diaphragm check valve D-6 with flowrate of 0.98 gpm @ 30 psi D-8 with a flowrate of 1.7 gpm @ 30 psi (given above parameters number of nozzles is 41 and 24 respectively)
Nozzle position	Pointed to the rear, angled down 45 degrees. With nozzle down in flight, the nozzles are pointing straight back.
Length of boom	32 feet (7/8 of rotor length - some recommend no more than 6/8)

Half Spray Boom

Western Helicopters has the capability of spraying from half the boom only. With an electrically activated solenoid switch, the pilot can terminate spray from the left or right side of the aircraft during flight. The spray atomization remains the same but the flowrate and swath width are cut in half. This is not new technology but it is relatively new to forestry and agricultural spraying. In fact we do not know of this having been used on USDA Forest Service contracts. Norm Parker mentioned that the half boom capability is required on industrial forestry contracts. Why would one want to spray from only half the boom and reduce aircraft productivity? Basically, to increase precision of delivery to the target and reduce chances of spray intrusion. Delivery along block boundaries, waterways, roads and other sensitive areas can be more precise and controlled, thus narrowing widths of protective buffer strips. There is also significant advantage of using half boom when spraying steep slopes to reduce spray drift, especially when the winds are downslope and perpendicular to the flight direction. Only the upslope boom is activated. The downslope boom, which would atomize drops higher above the ground, making them more prone to drift, would be eliminated. It should be noted that swath guidance becomes more critical when the swath width is reduced from 40 feet to 20 feet.

Aircraft Guidance and Block Marking

Reconnaissance is made of the block before spraying to evaluate how best to apply the spray and to identify features to be used as guidance. Snags and trees left in the blocks, lanes left by site preparation ripping, and other features are used as reference points to assist pilots in maintaining uniform lane separations. Western Helicopters does not currently use on-board global guidance systems (GPS), but they do use hand-held GPS systems to locate block corners. White panels (4

ft x 4 ft) placed on the ground are sometimes used to mark corners, when other features are missing or when blocks cannot be visually distinguished from adjoining blocks. Marking tape (white, orange or yellow) stretched horizontally is used to delineate boundaries.

Drift Control Adjuvants

Adjuvants like Nalco-Trol are used at rates of 4-6 ounces per 100 gallons to increase drop size and reduce number of drops in the driftable drop range (those less than 160 micrometers). The increase in drop size negatively influences coverage and control. More spray is also deposited in the forest canopy top than would be the case if smaller drops were sprayed (small drops are more likely to penetrate the canopy).

Other Liquid Spray Systems

Other systems used to apply liquid herbicides by aircraft are the Delevan raindrop nozzle (which attaches to a check valve system), the Microfoil boom, and the Thru Valve Boom (TVB). These systems have relatively large orifices, thus producing large-drop sprays equal to or larger than those produced by the D-8 jet nozzle. For forestry work in the Northwest and Northern California, using these larger-drop producing systems, Norm Parker indicates that the spray swath is confined to the point that there would likely be more skips with diminishing control and more drops would hang up in the upper canopies.

Dry Herbicide Application

Pronone 10G (10% hexazinone) is applied by a slung bucket, produced by Isolair of Oregon, at the rate of 25-30 pounds per acre depending upon soil type. This formulation is registered for forest use in California.

STATE-OF-THE-ART IN NEW ZEALAND

It sometimes helps to take a look at how others are conducting jobs similar to ours; therefore we thought it of interest to summarize aerial herbicide practices in New Zealand forestry. The topic has been reviewed by Richardson and Ray (1994), from which the information in this section is extracted and summarized. New Zealand has an aggressive forest plantation program with production on 1.3 million hectares. *Pinus radiata* is the dominant species composing 89.9 percent of the plantings (New Zealand Forest Owners Association 1994). As in the Northwest and other places in North America, New Zealand forest managers share the concern of herbicides impacting the environment and the costs of applying herbicides, and there is continued pressure to reduce reliance on herbicides and to seek alternatives. Although aerial application is the dominant method, on a per hectare basis, of applying herbicides, ground spot treatments are being used and evaluated. To address these and other forestry research needs, New Zealand supports an active research program at the Forest Research Institute, Rotorua, on the North Island. Their aerial application practices, summarized by Barry (1993), are similar to those reported by Norm Parker. In applying herbicides by air, helicopters are used almost exclusively because of the steep terrain and high productivity ability. The Bell 205 Jet Ranger is the most common with others including the Hughes 300 and 500, Hiller 12E, Aerospatiale Lama, and Squirrel (Ray et al 1992).

Drift reduction is always a major concern and as such, sprays are generally applied using what are considered to be "low-drift" nozzles. Because of the large droplets produced by most low-drift nozzles, there has always been the trend to use high application volumes (usually between 200 to 350 L/ha) to ensure good coverage is achieved on hard-to-kill brush weeds. However,

over recent years there has been a gradual trend toward lower spray volumes (generally between 50 to 150 L/ha). Although this gives a reduction in spray coverage on the target plant, superior chemicals and adjuvants clearly compensate for this factor, and there is the added benefit of increased productivity (area sprayed per hour). In terms of hectares of forest land sprayed, foaming nozzles are probably the most common nozzle, followed by conventional D8-45 nozzles and then D8-46 nozzles. Results of recent trials have confirmed that foaming nozzles significantly reduce drift potential compared to the D8-45, so it is likely that they will continue to be used. However, in situations where drift control is paramount, nozzles which will reduce drift even further would include D8 straight back or Raindrop (Delevan Co.) nozzles. The half-overlap flying technique is generally used to reduce coefficient of variation. On flat sites, some form of flight line marking (e. g. flagmen) is not uncommon, but this is often impractical on steeper terrain. The potential of global positioning system (GPS) as an electronic aid to increase the precision of herbicides is under investigation.

To identify techniques to minimize herbicide spray drift, a considerable effort has gone into applying and validating the FSCBG spray application simulation model (Teske et al. 1993) to New Zealand conditions. The model has been used to provide general recommendations for minimizing spray drift, and for selecting spray equipment and methods of maximizing productivity. It has proven to be an excellent training tool (there are 16 trained users in New Zealand, with a further two from Australia having been through the New Zealand training course), and it is hoped that using the model operationally will be accepted by regulators as evidence of applying "best practices." Aerial simulation by computer using the FSCBG model is reviewed in a bulletin produced by the Forest Research Institute (New Zealand Forest Research Institute 1993).

NEW TECHNOLOGY

We are reminded at this point that the focus of this paper is new technology that can be used to improve the efficacy, safety and efficiency of aerial application of herbicides in California forestry. Norm Parker has provided us with the state-of-the-art as summarized above and likewise we have reviewed application practices in New Zealand. These include selection, positioning and use of nozzles that reduce number of small drops; use of helicopters that can maneuver safely and precisely over steep terrain; use of drift reduction adjuvants in the tank mix; keeping the release height as close to the ground as safety will allow; and use of half boom to reduce spray drift. Under new technology we will summarize work on herbicide drop size conducted in California by Ed Fredrickson and Mike Newton, an aerial efficiency model, the spray drift, dispersion, and drift model, and nozzles and atomization.

Ed Fredrickson and Mike Newton Study

The Fredrickson/Newton study (Fredrickson and Newton 1995) was conducted in the Northern Sierras and Oregon to evaluate the efficiency of several silvicultural herbicides. A summary of the study is quoted from Mike Newton.

"This paper is in two major sections. Section I reports a series of experiments in evergreen shrub, deciduous shrub and herbaceous forest vegetation where several application factors influenced efficiency of silvicultural herbicides. Volume per acre of diluent influenced efficacy on shrubs infrequently. When suboptimum dosages of glyphosate were applied to salmonberry, 5 gallons per acre (gpa) was more effective than when applied in 10 gpa. Conifer damage was related to drop size and inclusion of surfactant. Ponderosa pine damage was generally increased when large drops (900 micrometers) were used as compared with smaller drops (< 600 micrometers). Drop size

seldom influenced damage to shrubs except for a weak trend for small drops (< 600 micrometers) to increase damage to whiteleaf manzanita, and large drops to enhance control of bear clover and greenleaf manzanita.

Both silicon-based (Silwet) and non-ionic (Activator 90) surfactants increased efficacy of glyphosate on evergreen shrubs in June, but not in April. Growth regulator emulsifiable ester formulations (triclopyr, diclorprop and fluroxypyr) were not changed in their efficiency by inclusion of added surfactants. Effects of all foliage-active products on ponderosa pine were increased by all surfactants tested, but Douglas-fir did not respond at the low doses tested. The only consistent factor influencing efficacy of atrazine or hexazinone on grasses or forbs was their solid vs. liquid state. In the clay-loam soils with sod-forming herbs, the 75 percent granular hexazinone was less effective than liquid hexazinone at the same rate of active ingredient when applied in April.

When testing combinations of drop size, volume, surfactant and dosage, specific effects of an individual factor often changed when changing another. Thus, it is sometimes difficult to generalize on the merits of a specific technology without listing the rest of the prescription.

Section II provides operational directions on how to use the application technology findings from the above experiments. A series of decision trees is used to show the array of herbicide options effective in a variety of situations. They illustrate how the information and products available to foresters can be used with maximum efficiency for a given objective. The decision trees are not all-inclusive, but focus on that part of the prescription process involving herbicide application technology."

Aerial Spray Efficiency Model

The USDA Forest Service has developed a computer model called CASPR (Computer Assisted Spray Productivity Routine) (Curbishley et al. 1993) based upon the Baltin-Amsden formula (Amsden 1960) that estimates the cost of an aerial spray operation on a personal computer (Banaugh and Ekblad 1984). The model predicts costs based upon several inputs to include application rate, ferry time, turn time, payload, and swath width. The model was evaluated on a gypsy moth eradication project in Utah, where it was able to predict operation time within 23 percent of actual, thus providing a basis to quickly estimate costs. We see this as a useful tool for resource managers who want to estimate application costs, for contracting officers who need to estimate contract costs, and especially for applicators who need to prepare bids and manage a profitable business. The model is available from the authors at no charge.

Aerial Spray Drift, Dispersion and Deposition Model

The Forest Service Cramer-Barry-Grim model (FSCBG) (Teske et al 1993) is being used by the USDA Forest Service, its cooperators, consultants, and New Zealand to plan and support aerial applications, and by researchers who are studying movement of spray materials in the atmosphere. FSCBG predicts the drift, dispersion and deposition of sprays released from aircraft, based upon a description of the tank mix, atmosphere, aircraft, atomization, and volatility of the spray material. The model is also a total accountancy model able to predict the amount of spray material that has volatilized, deposited or remained airborne. The model uses Lagrangian functions for deposition on the ground, crops and trees in the near-field and Gaussian functions for dispersion in the distant field. It has a user friendly format and is available, along with a user manual, from the authors. Rafferty (1984), under a USDA Forest Service contract, was the first to apply FSCBG to a herbicide problem by producing graphic displays showing off-target movement as a function of wind and release height.

FSCBG is currently being adapted as the core model for decision support systems by the USDA Forest Service and New Zealand Forest Research Institute (Teske 1995). In addition FSCBG is under consideration by the Spray Drift Task Force (an industry-based venture) (Valcore 1994) and Canada to satisfy pesticide regulatory needs. FSCBG's application to forestry was reviewed by Barry and Teske (1993) at a vegetation conference in New Zealand. Smith et al. (1993) developed drift reduction guidelines based upon FSCBG and two other codes. Technology transfer of the model and its connected decision support systems continues (Teske 1995).

FSCBG Model Demonstrations

FSCBG model runs were performed at the request of Ed Monnig, pesticide specialist, USDA Forest Service Northern Region, and Joe Sherlock, silviculturist, Pacific Southwest Region. Ed's question was width of buffer strips to protect a stream from drift of an aqueous herbicide, Tordon 22K spray, and Joe's question was deposition and drift pattern of a dry herbicide, Pronone 10G. These are referred to respectively as Problem A and Problem B.

Problem A: Demonstrate effects of a full spray boom vs half spray boom on lateral displacement of a liquid herbicide (Tordon 22K) applied by helicopter on a steep slope. The half boom is the one on the uphill side, and is therefore closer to the ground.

FSCBG Basic Inputs:	Hiller 12E Soloy
	Application Rate -- full boom 5 gpa; half boom 2.5 gpa
	Drop Atomized from D-8 jet nozzle
	Wind Speed -- 6 mph
	Temperature -- 70 deg F
	Relative Humidity -- 60 percent
	Wind Direction -- quartering
	Swath Width -- full boom 50 feet; half boom 25 feet
	Aircraft Speed -- 50 mph
	Volatile Fraction -- 99 percent

Variables Demonstrated: (1) Effects of release height on lateral displacement from full boom (at 75 percent of rotor length); (2) Effects of release height on lateral displacement from half boom (37.5 percent of rotor length) on the upslope side of the helicopter.

Predicted Results (Figures 1A, 1B, 1C and 1D): We have predicted the lateral displacement and illustrated the deposition pattern of both drops per square centimeter and gallons per acre from a single swath of spray deployed from a full boom. Figure 1A illustrates deposition expressed in drops per square centimeter. It demonstrates less deposition from the higher releases, due to effects of evaporation, with a greater shift of the drops downwind from the higher release compared to the two lower releases. It is interesting to note, however, that drift 30 feet beyond the helicopter track is about the same for each of the three release heights. This may be due in part to the quarter wind in lieu of our experiences with spray movement associated with 90 deg crosswinds. Figure 1B illustrates deposition and the lateral displacement pattern with deposition expressed in gallons per acre. The 10 foot release pattern is bimodal with a spike in the center. This is due to the ground effects on the helicopter vortex, accentuated by the low release height. The 25 foot release is preferred; however, its jagged deposition pattern would benefit from a stronger crosswind to smooth-out the deposition pattern. There is more lateral displacement demonstrated on the higher release. Figures 1C and 1D demonstrate the effects of using only a half boom that reduces swath width and application rate in half, but provides the pilot with more control in placing and depositing the spray. The half boom used is the one on the upslope, and in this scenario, upwind side of the helicopter; therefore, the one closest to the ground. Most of the spray, as demonstrated, is deposited on the upslope and upwind side of the aircraft as intended. Note that for the two higher releases there is a shift of the mean deposit downslope and

downwind accompanied by more lateral movement. Is there a difference in drift potential between the full and half boom and release height? The answer is best presented in a summary table (Table 3).

Problem B: Predict effects of release height on deposition pattern of a granule herbicide (Pronone 10G) from a bucket dispenser slung from a helicopter.

FSCBG Basic Inputs: Hiller 12E Soloy
 Helicopter Speed -- 50 mph
 Application Rate -- 15 lbs per acre
 Wind Speed -- 3 mph
 Wind Direction -- crosswind

Variables Demonstrated: Effects of release height on Pronone 10G dispensed at 60 and 100 feet above terrain under a 3 mph crosswind.

Predicted Results (Figures 2A and 2B): Swath widths based upon 15 lbs per acre recovery are 20 feet for the 60 foot release height and 18 feet for the 100 foot release height. Lateral (downwind) spreads from the center of the helicopter release track are 19 feet for the 60 foot release height and 23 feet for the 100 foot release height. While the range of 19 to 23 feet is quite narrow, it becomes important in deciding swath spacing and executing precision application along boundaries and streams.

Problems A and B illustrate some of the capabilities of the FSCBG model by applicators to evaluate equipment performance and to develop operational strategies.

Nozzles and Atomization

In the 1980's the USDA Forest Service contracted Professors Wesley Yates and Norman Akesson at the University of California (Davis), Department of Agricultural and Biological Engineering, to conduct wind tunnel test with the PMS laser system, to characterize the atomization of numerous tank mixes and nozzles. Results of these characterizations were reported by Skyler and Barry (1991). Of particular interest here were the characterizations by Yates et al. (1985a) conducted for the USDA Forest Service on atomization of simulated herbicide tank mixes by the D-8 Jet and D-8-46 hollow cone nozzles (Table 1). The table shows the drop size expressed by VMD (volume median diameter) for 0 degree back and 45 degrees down-and-back orientation to the airstream. As expected, larger drops are produced when shear is reduced by orienting the nozzle straight to the rear of the helicopter. The 0 degree orientation significantly reduces the percent of driftable drops (those less than 154 micrometers in diameter). Table 1 shows that the D-8 nozzle produces a larger VMD and fewer driftable drops than the D-8 with the 46 whirl plate that produces a hollow cone atomization.

On another study conducted by Yates et al. (1985b) for the USDA Forest Service, they looked at the effects of Nalco-Trol drift control adjuvant on atomization, specifically the drop size expressed in VMD, and the percent volume and the percent of total drops in drop sizes less than 154 micrometers. The characterization was performed with the D-8-46 nozzle and not the D-8. Nevertheless, results (Table 2) demonstrate the reduction in volume and total drops that contain driftable drops with use of Nalco-Trol. A very important point needs to be made here. The characterization was done under essentially no shear conditions with the nozzles oriented straight to the rear. Effectiveness of Nalco-Trol and other similar polymers in reducing driftable drops diminishes with increased shear (Yates et al. 1985b). Another point to remember, as pointed out by Norm Parker: coverage and herbicide efficacy are compromised as the atomization is increased. Many variables influence this but the drop size cut-off is probably around 1000 micrometers VMD. Newton (1994) discussed adjuvants during his presentation at the National

Pesticide Use Management Course at Marana, AZ. Fredrickson and Newton (1993 and 1995) also reported on the relationship of spray volume, dose, surfactant and drop size to herbicide efficiency.

DEVELOPING TECHNOLOGY

Developing technology is referred to as that which is not fully operational or has not been adequately tested or demonstrated. Technology discussed below are mostly enhancements or extensions to the FSCBG model that have direct application to aerial herbicide application.

Global Positioning System and Real-Time Spray Monitoring

Treatment block marking and maintaining evenly spaced swaths, while applying spray, have been the challenges to aerial application of herbicides and other materials applied by air. Block marking methods were recently reviewed by Kilroy and Thistle (1994). Most of the listed methods are long-standing and practical but do not aid sufficiently to meet today's standards. Richardson et al. (1993) reported that a high level of spatial deposit variation can be expected during aerial herbicide application, noting that in a typical application, less than 20 percent of the area is likely to receive a herbicide dose within 20 percent of the application rate. Real-time, in-flight capabilities are under initial development by the USDA Forest Service and its cooperators.

The field of GPS is a rapidly growing technology based upon receipt of signals from multiple satellites. Differential corrections by ground-based systems can increase the accuracy down to 1 meter. With differential correction the system is referred to as DGPS.

Current hardware range from simple systems that keep track of the aircraft flight path (for later playback), to more sophisticated aircraft navigational systems that provide a means for the pilot to correct the aircraft flight path while spraying. Thistle et al. (1994) reported on an evaluation of differential global navigation systems in mountains of western Montana. The topography and mountain weather challenged the systems and we do not believe that the technology is ready for full operational deployment in mountainous terrain using its full capabilities. Other features such as recording flight paths and finding the block corners are, for the most part, operational and recommended.

An enhanced capability based upon connecting DGPS to FSCBG is under development. A very fast version of the USDA Forest Service aerial application prediction model FSCBG will be developed (Teske et al. 1994). This version of the model (FSCBG/RT, RT for real-time) will run in real-time on the on-board computer and/or ground-based computer/monitor, and will access spray volume, meteorological conditions, release height, and aircraft direction, to predict the effects of aircraft speed, flight profile, pump pressure changes, flow rate, and other data, on the spray plume, the latter being monitored on a screen by the pilot or by a ground monitor. This prediction will be returned to the navigation and monitoring system for possible corrective action. The end product will be a system that will track the aircraft, display the spray swath width, and visualize the pesticide spray deposition and movement, all in real-time.

To provide a quantitative feel for the usefulness of the proposed FSCBG/RT model, a sample calculation is provided. Separate computational blocks have been programmed into a Zenith Z-Note 425Ln+, a full 486 computer (portable) operating at 25 mHz. The separate computations break down as follows:

1. Computation of the average release height, temperature and relative humidity, by updating ten minutes of data (one data point taken every ten seconds, dropping the oldest data point and averaging) takes 0.22 sec to initialize, and 3.5 msec per update.
2. Computation of the average wind speed and wind direction, and the azimuthal standard deviation, by updating ten minutes of data (one data point taken every second, dropping the oldest data point and using an algorithm described by Teske 1992) takes 2.30 sec to initialize, and 3.6 msec to update.
3. Computation of the wetbulb temperature depression. For a typical nozzle D8-46 with 24 drop size categories (Skyler and Barry 1991), and a temperature of 20 deg C and 80 percent relative humidity, this procedure recovers a source strength fraction of 0.890 for a release height of 15 m in 3.8 msec.
4. Computation of the predicted concentration at a single downwind location (off the plume centerline) is found in 0.1 msec. After initialization (which can be done before spraying begins), the total update computation takes 12.6 msec.

Decision Support Systems

Decision support systems (DSS) are being developed for the resource manager to assist them in making sound decisions within a world encumbered with information and options. New Zealand (Mason et al. 1991; Mason 1992) has developed a DSS for herbicide selection and alternative control strategies. At the initiation of the New Zealand (NZ) Aerial Spray Modelling Research Group, a group made up of members from NZ Forest Research Institute, NZ forest companies, DowElanco, Monsanto, and the NZ agricultural aviation industry, New Zealand will be coordinating the development of a DSS for aerial application of herbicides (Richardson 1994; USDA Forest Service 1994). The USDA Forest Service will be a cooperator with the Forest Research Institute and the NZ Spray Modelling Research Group in development of the DSS. Our DSS will use FSCBG as the foundation upon which the DSS will be built. As pointed out by Richardson (1994), the DSS will be a practical tool based upon solid assumptions that will provide information on potential environmental impact of herbicides, biological impact on target plants, and cost of application. In essence we will be extending the power of the FSCBG model to predict biological effects, both wanted and unwanted, for function of cost. Graphic outputs, designed for ease of understanding and application, will, as an example, show biological response as a function of dose deposition and width of buffer strips needed to protect sensitive areas. The practicality of the DSS will virtually ensure that the system will be used when environmental impact and costs are at issue, which, of course, is nearly always. A detailed study plan on development of DSS is being prepared jointly by NZ Forest Research Institute and the USDA Forest Service. The DSS will serve as a model for other DSS systems using FSCBG as the base model.

SUMMARY OF DRIFT MANAGEMENT METHODS

Numerous people have studied and reported on how to reduce drift of aerially released pesticides. It is the subject of government regulations, pesticide labels, agricultural research bulletins, pesticide training, pesticide certification examinations, manufacturer guidelines and handbooks, research proposals to U. S. Environmental Protection Agency, and lawsuits to name a few. The fact is, as long as we atomize material in the atmosphere, we will be challenged to manage drift. Drift is inevitable while, at the same time, drift is manageable. Listed below is the conventional, nothing-new, methods of managing (not controlling) drift, noting that label and other government regulations must be followed at all times.

1. Apply material as close to the target as practical. The shorter the travel time the less time atmospheric conditions have of moving the spray material to other locations. There is a trade-off in swath width and distribution of the spray on target, and the risk of skips and overdosing if too close to the target. Also, reduction in swaths increases costs. The FSCBG predictions presented in this paper demonstrate these effects.
2. Restrict nozzles to no more than 75 to 80 percent of the helicopter rotor or aircraft wing distance. This will reduce the amount of material that can become entrained in the rotor or wind generated vortex.
3. Atomize spray in large drops and reduce shear across the nozzle during atomization. This can be done in many ways, but the larger the drop spectrum the greater the chance for skips and on-target plant damage, and the higher the application costs due to narrower swath widths and in some cases increased application volumes. Use of conventional hydraulic nozzles, oriented straight back to reduce shear across the orifice, helps to reduce the driftable fine drops. The favored nozzle in drift sensitive situations is the D series without whirl plates, such as the D-6 and D-8. Other equipment designed to produce large drops are the Raindrop, foaming, TVB boom, and Microfoil boom nozzle and systems. These, when used as intended, disperse the spray to the rear, thus reducing shear. Generally these systems produce spray in drop VMDs over 1000 micrometers so be cautioned that coverage might be poor or overkill a problem. Boom pressure tends to influence atomization -- higher the pressure, smaller the atomization. Generally we look for 30 psi pressure. Forward speed of the aircraft influences atomization as it relates to shear across the nozzle. The higher the speed, the greater the shear. For nozzles oriented straight back, this is not a problem for helicopters because of their relatively slow flight speed.
4. Consider the atmospheric conditions. Everyone knows that air movement causes material to move in the atmosphere, the greater the velocity the greater the movement. Winds over about 3 mph which have a steady direction should be viewed as the sprayer's friend. Such winds can carry the spray from non-target areas to target areas, they are relatively predictable, and they help distribute the spray more evenly across the target. In some situations they assist in impacting the spray on the target. Winds below 3 mph, and those that are variable, are dangerous. These should be avoided when aerial spraying if possible. Much spray is applied under conditions that were called "ideal" in the past -- that is, in early morning or evening when a ground-based inversion had developed. Large drops can easily penetrate such inversions, but remember the tables that show most -- yes, most -- of the total drops, even from the jet nozzles, are in the driftable range that can ride the top of the inversion layer and drift. Under such conditions a highly concentrated cloud can drift or meander, causing problem damage to non-target species. There have been incidents reported where long range drift has caused damage at distances over 10 miles (Akesson et al. 1992 and Penkenpaugh et al. 1974). The spray was likely released into low intensity winds, below inversions, and in nonvented valleys or canyons. Temperature differences in the vertical profile can have profound effects on drift. This subject is complicated and cannot be adequately treated in this paper.
5. Adjuvants as drift control agents have also been mentioned in this paper.
6. Trees and shrubs can serve as a drift barrier by filtering spray. Unfortunately, there is limited data to argue this for aerial application. This is another reason for maintaining vegetation near water and other sensitive areas.

CONCLUSIONS

This paper has reviewed the state-of-the-art and new technology of applying herbicides by air to forests, primarily in western United States and New Zealand, with focus on California. The USDA Forest Service has not conducted research specific to aerial application of herbicides since the late 1970's; nevertheless, technology developed by the USDA Forest Service for application of insecticide, and especially others to include applicators, universities and other governments listed above, can be assimilated and applied to California forestry. We have attempted to bring forth technology that is currently available and project availability of existing and developing technology that may be available in the near future. We believe that the technology reviewed in this paper demonstrates that the knowledge and understanding is in place for environmentally safe, efficacious, and economical use of aerially applied herbicides to meet today's expectations. The authors take sole responsibility for the information in this paper and appreciate your comments and other feedback.

ACKNOWLEDGMENTS

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Table 1. Percent volume of spray in driftable drop sizes (< 154 micrometers), atomized at 30 psi (after Yates et al. 1985a).

Nozzle Type	Simulated Herbicide Tested	Flow Rate (gpm)	Nozzle Angle Relative to Air Stream	VMD (μ m)	Percent Volume < 154 μ m
D8 Jet	Esteron	1.62	0	1036	0.83
	Esteron	1.62	45	589	8.9
	Garlon	1.62	0	1130	0.69
	Garlon	1.62	45	471	5.6
	Roundup	1.62	0	1208	0.61
	Roundup	1.62	45	587	7.9
	Water	1.8	0	1247	0.83
D8-46	Esteron	1.5	0	492	2.3
	Esteron	1.5	45	513	5.9
	Esteron	1.5	90	437	6.4
	Garlon	1.5	0	481	2.7
	Garlon	1.5	45	415	5.0
	Garlon	1.5	90	382	6.7
	Roundup	1.5	0	462	3.9
	Roundup	1.5	45	433	5.7
	Roundup	1.5	90	422	6.1
	Water	1.8	0	501	2.5
	Water	1.8	90	442	6.8

Note:

0 degrees nozzle angle refers to nozzle pointed straight back, or opposite to aircraft forward direction; 45 degrees refers to back and down 45 degrees.

VMD is the volume medium diameter: 50 percent of volume is in drops smaller than the VMD, and 50 percent of volume is in drop larger than the VMD.

Table 2. Effects of Nalco-Trol on atomization, drop size and driftable spectrum, D8-46 nozzle at 40 psi, 0 deg to the airstream and 50 mph air speed (after Yates et al. 1985b).

Nozzle Type	Oz of Nalco-Trol per 100 Gal Water	Flow Rate (gpm)	Nozzle Angle Relative to Airstream	VMD (μm)	Volume < 156 μm (percent)	Drops < 156 μm (percent)
-----	-----	-----	-----	-----	-----	-----
D8-46	0	1.84	0	501	2.46	72.32
	3	1.38	0	714	1.35	65.90
	6	1.38	0	873	0.87	63.80
	9	1.38	0	1099	0.42	56.09
	12	1.38	0	1150	0.25	55.55

Note:

0 degrees nozzle angle refers to nozzle pointed straight back, or opposite to aircraft forward direction; 45 degrees refers to back and down 45 degrees.

VMD is the volume medium diameter: 50 percent of volume is in drops smaller than the VMD, and 50 percent of volume is in drop larger than the VMD.

Table 3. Lateral displacement (in feet) of spray downwind and downslope from center track of Hiller 12E Soloy helicopter applying Tordon 22K under a quartering 6 mph wind as a function of release height, with spray deposition units expressed in drops per square centimeter and gallons per acre.

Release Height	Displacement: Full Boom		Displacement: Half Boom	
-----	Drops	Gallons	Drops	Gallons
-----	-----	-----	-----	-----
10 feet (5 feet)	170	35	10	1
25 feet (13 feet)	170	45	10	4
50 feet (25 feet)	170	60	90	10

Note: Lower release height assigned to the half boom as the upslope portion of the boom is closer to the ground than the mean height of the full boom.

Figure 1A - Problem A - Predict the drift of Tordon 22K based upon drops, from a full boom (75% of helicopter rotor length) as function of release height under a 6 mph quarter wind.

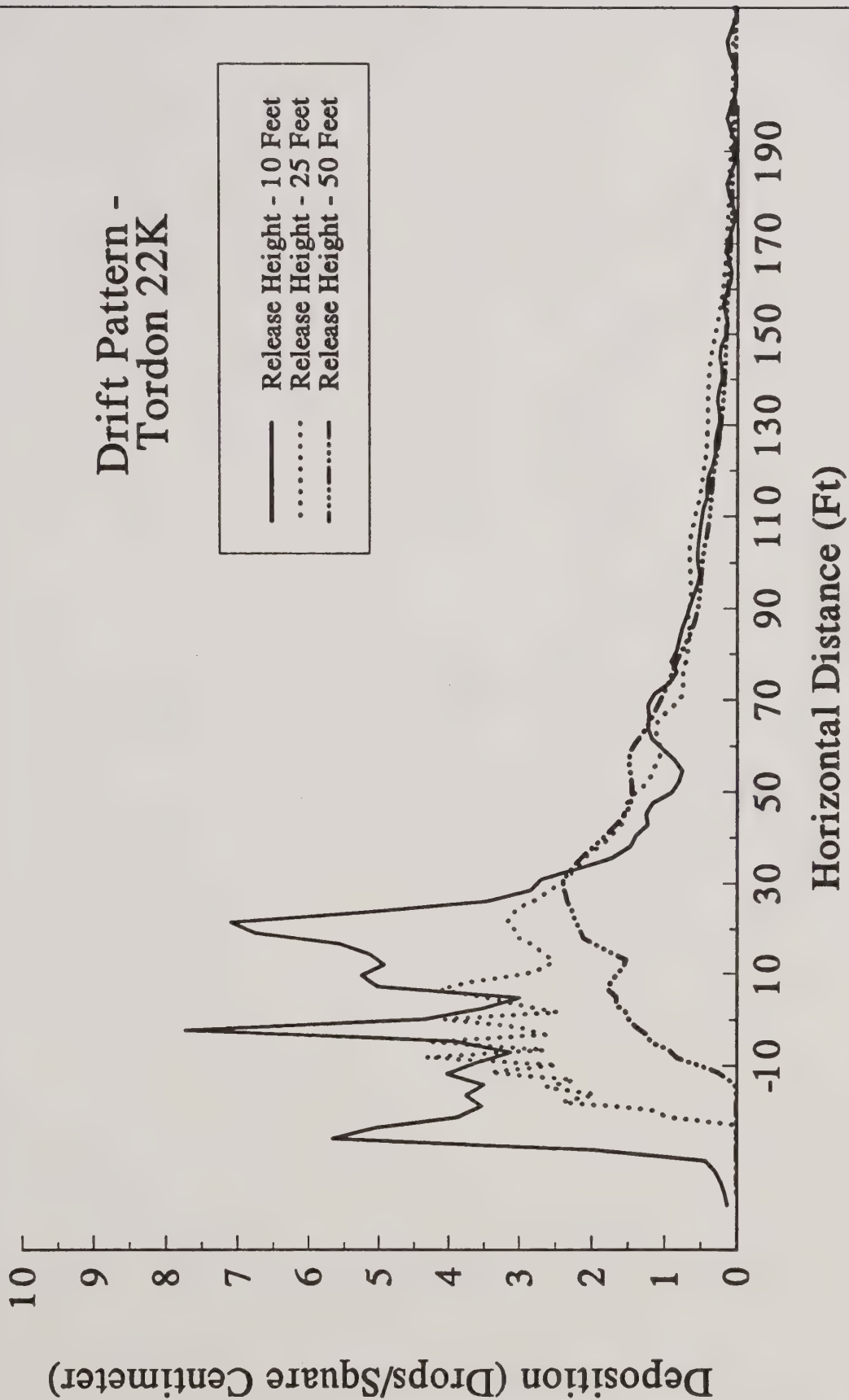


Figure 1B - Problem A - Predict the drift of Tordon 22K based upon gallons per acre, from a full boom (75% of helicopter rotor length) as function of release height under a 6 mph quarter wind.

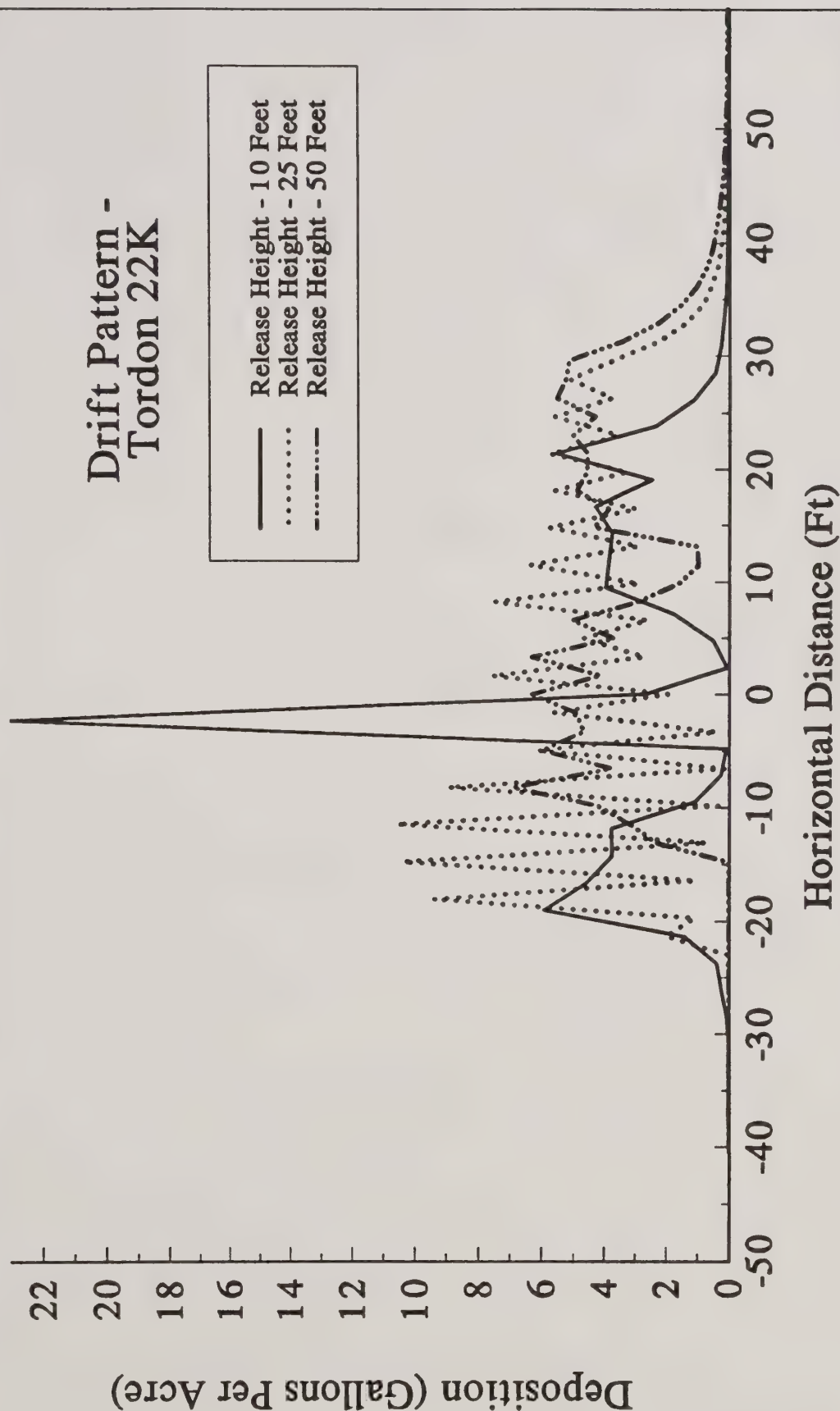


Figure 1C - Problem A - Predict the drift of Tordon 22K based upon drops, from a half boom (37.5% of helicopter rotor) as a function of release height under a 6 mph quarter wind.

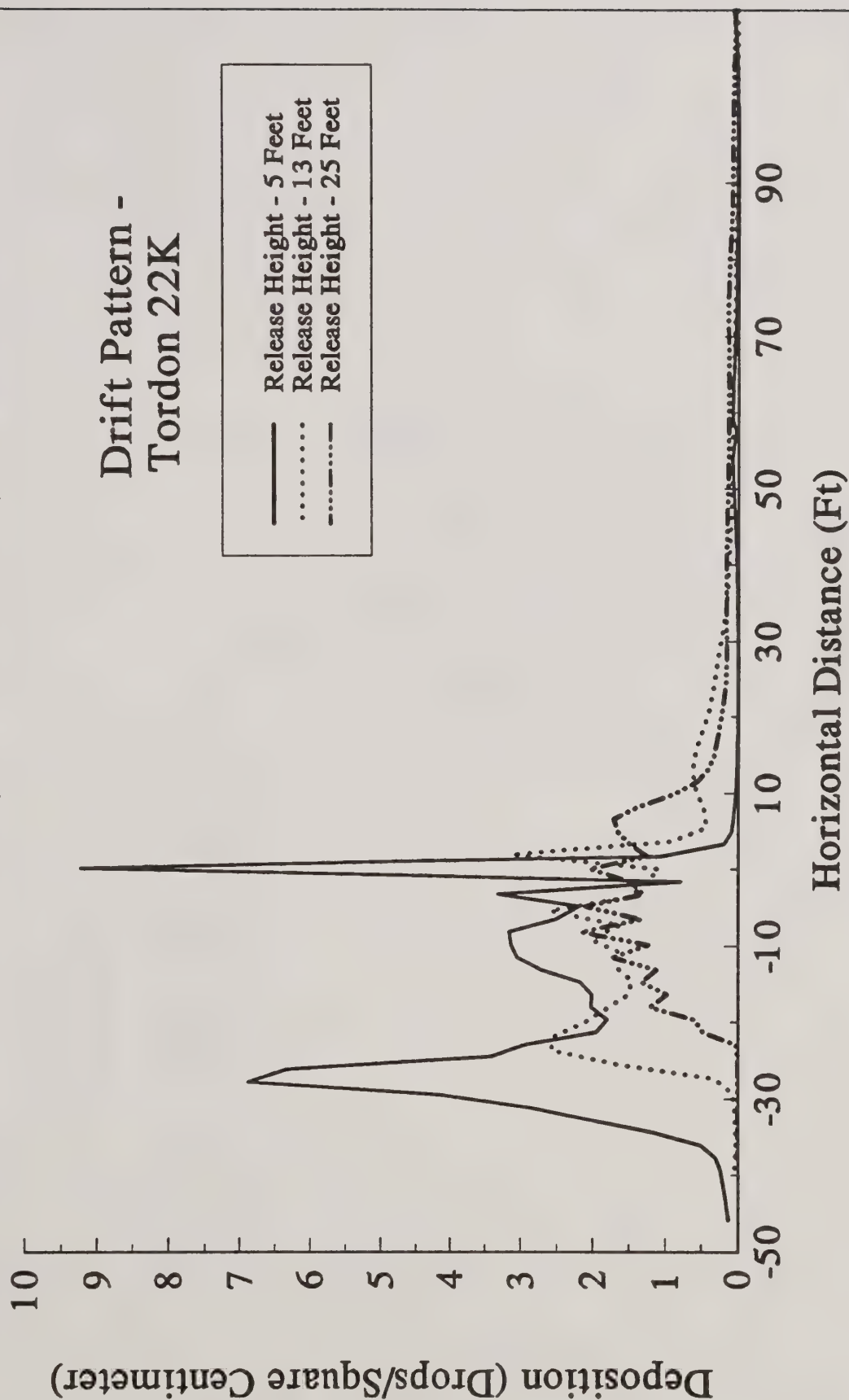


Figure 1D - Problem A - Predict the drift of Tordon 22K based upon gallons per acre, from a half boom (37.5% of helicopter rotor length) as function of release height under a 6 mph quarter wind.

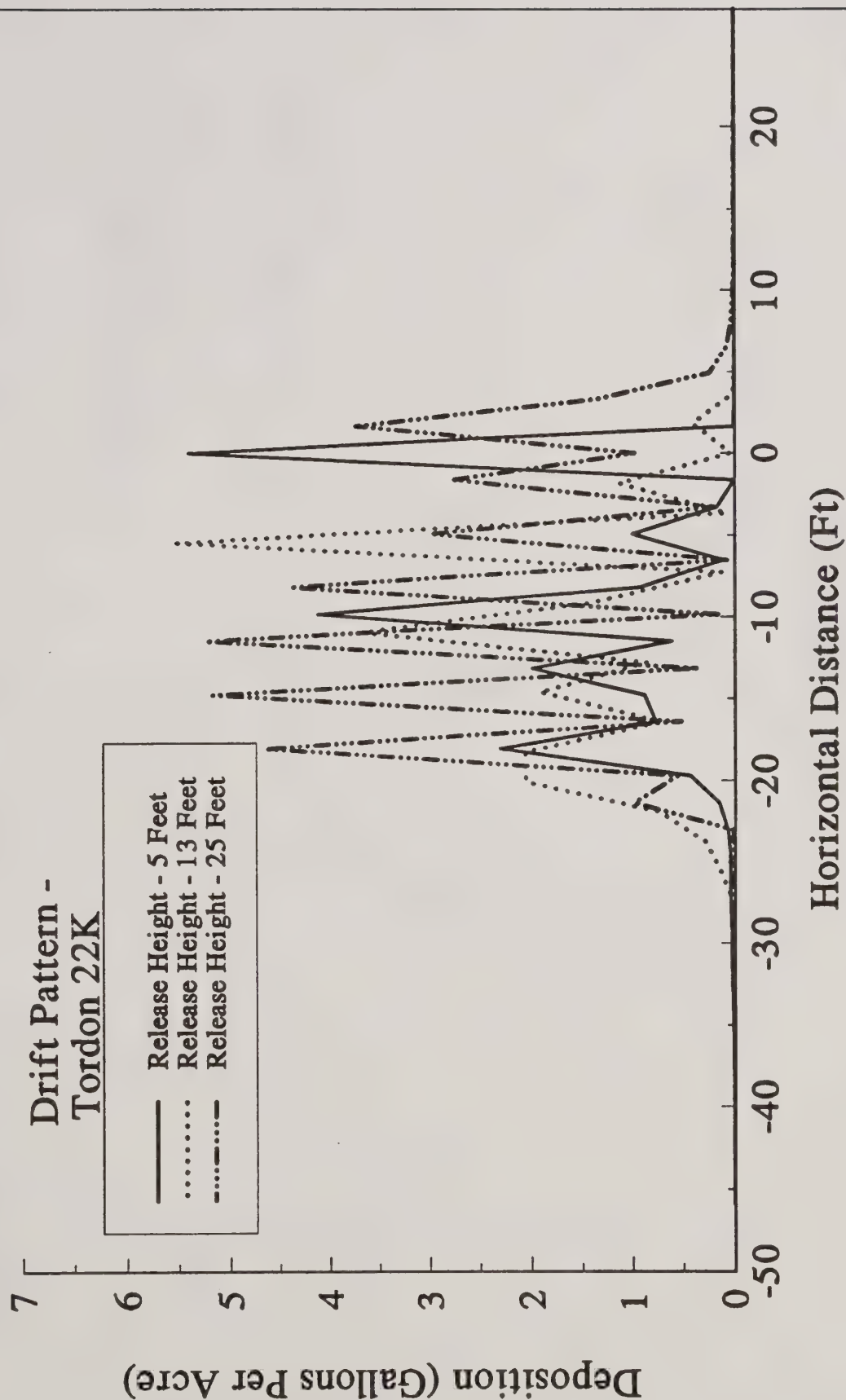


Figure 2A - Problem B - Predict the distribution of Pronone 10G as function of release height and 3 mph crosswind

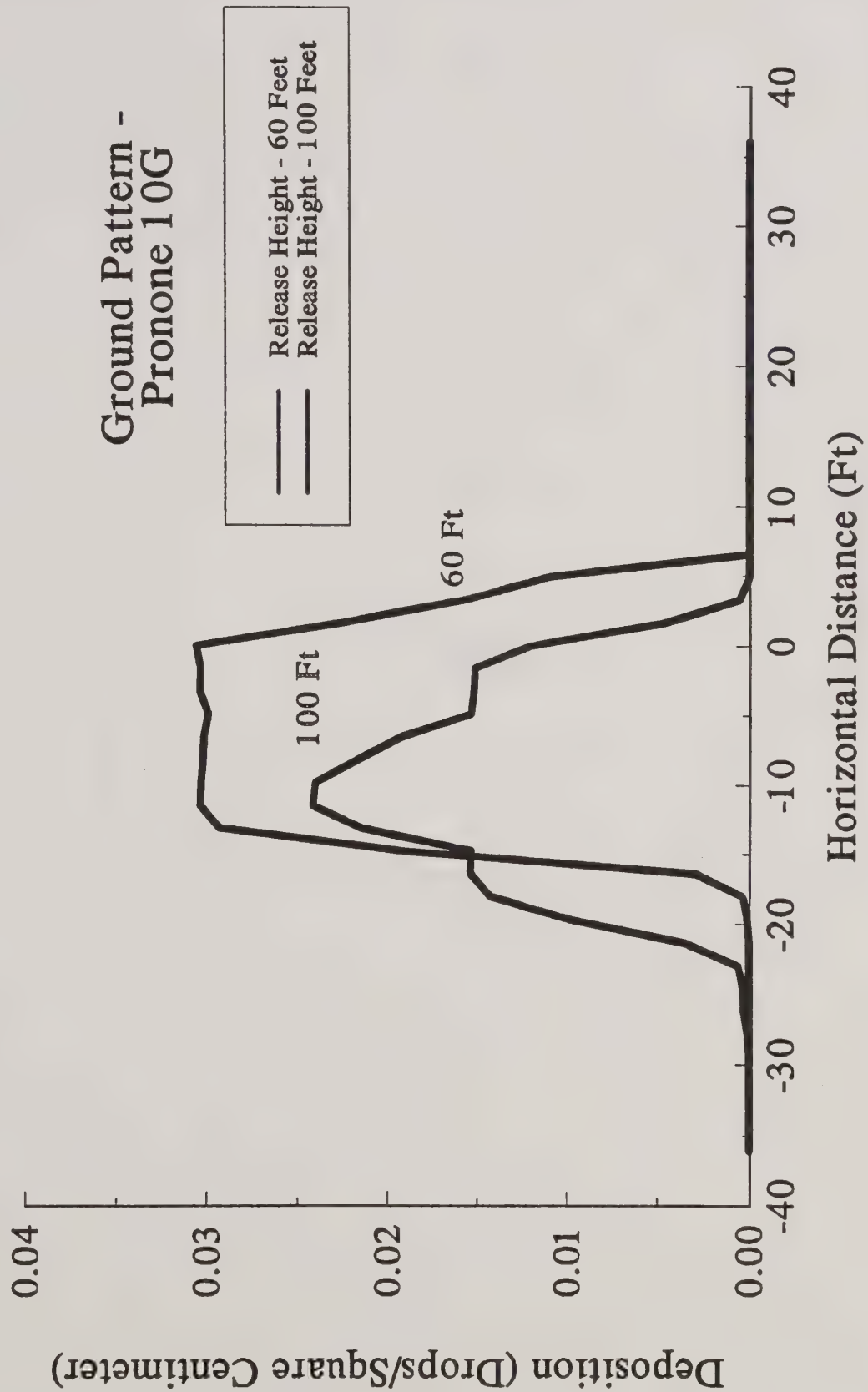
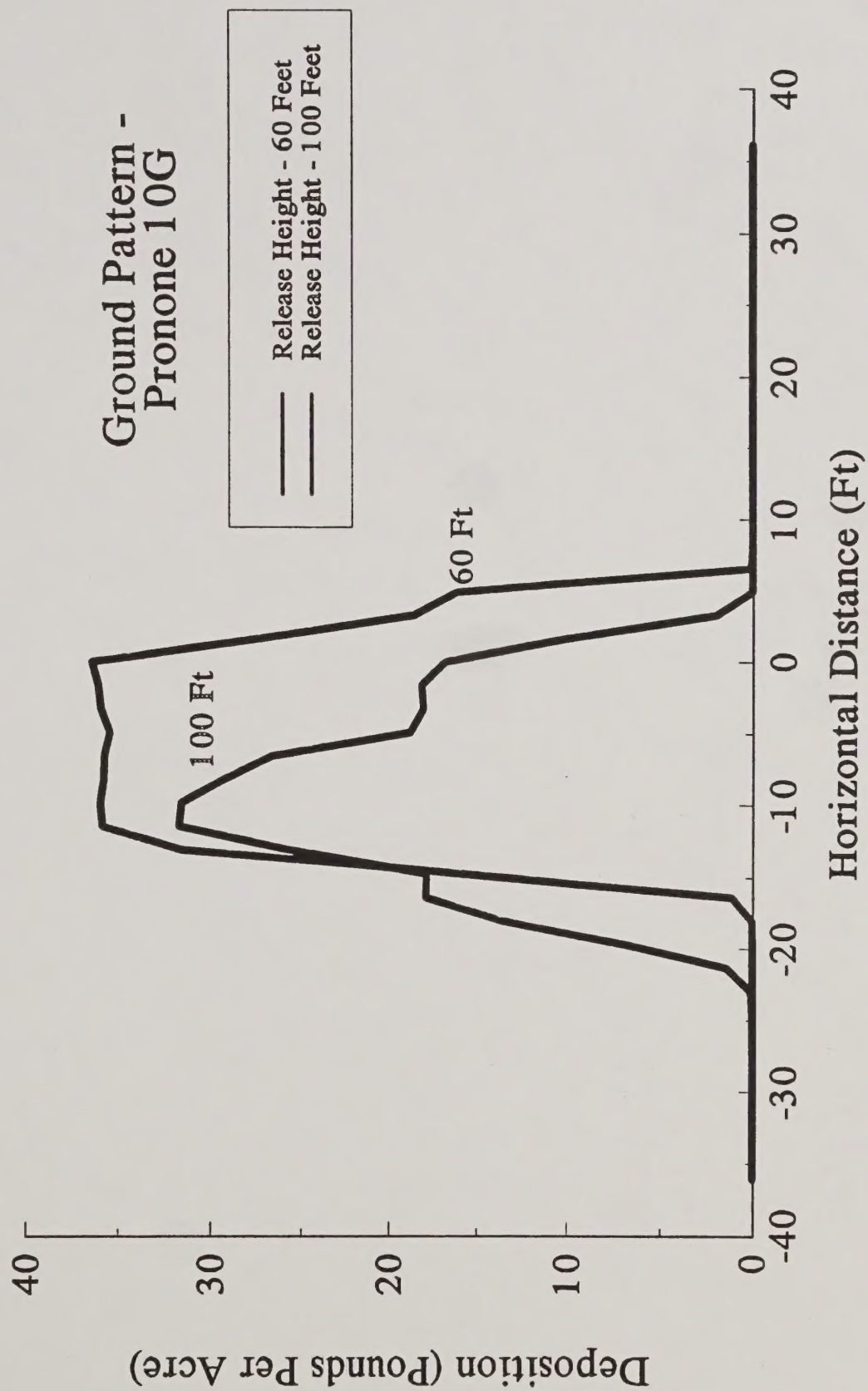


Figure 2B - Problem B - Predict the distribution of Pronone 10G as function of release height and 3 mph crosswind



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